Fermi National Accelerator Laboratory

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Characteristics of the Beam During Collider Run II *

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This note describes some of the characteristics of the beam in the collider during the last collider run and as such it provides a base line for comparison with the beam properties measured during future collider runs.

The measure of accelerator performance, during collider operation, is the luminosity which can be calculated from the measured beam parameters. (We also need to know the lattice functions but the problem of determining these is outside the scope of this note.) The luminosity $\mathcal{L}$ can be written in terms of the characteristics of the beam as: [1]

$$\mathcal{L} = \mathcal{C}(L) \cdot N_p \cdot N_{\bar{p}} / (\beta_h \cdot \epsilon_h \cdot \beta_v \cdot \epsilon_v)^{1/2}$$

where:

$\mathcal{C}(L)$ A function of the bunch length, L.
N_p The number of protons in the bunch.
$N_{\bar{p}}$ The number of anti-protons in the bunch.
ϵ_h The horizontal emittance of the bunch.
ϵ_v The vertical emittance of the bunch.
β_h and β_v are the values of the amplitude function at the interaction point.

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[1] This formula cannot be used to calculate the luminosity when there is more than one proton and anti-proton bunch or when the p and $\bar{p}$ have different emittances but it does identify the beam parameters required to calculate the luminosity

This note will concentrate on those beam characteristics needed to calculate the luminosity. All the data described here have been culled from the COLL88 data base generated during Collider Run II. Only the data recorded during low-β operation on or after Nov. 6,1988 (store 1728) are used in this note (a total of 135 stores). [2] The data stored for each **ACNET** device was either averaged over a predetermined length of time (typically 15 minutes) or stored whenever the value of the device changed. Thus the bunch intensities and bunch lengths are averaged while the transverse emittances are recorded whenever they are measured.

The data of each bunch were fit to a polynomial in the time after the wires were first flown *after* the TEVATRON was at low-β. This is typically one hour after the time low-β was achieved. Thus I am *not* describing the beam characteristics immediately after the start of collisions in the TEVATRON.

[2] All the data are from the period during which we used the procedure to "kill unwanted beam". In this procedure beam in unwanted buckets was removed and the emittance of the p beam was deliberately increased to reduce the beam-beam interaction.

Bunch Intensities

The intensities of the 6 proton and 6 anti-proton bunches were measured by the **SBD** (**S**ampled **B**unch **D**isplay). The data were recorded by the data logger and these data were averaged over a 15 minute interval and stored in the data base. The intensity of each bunch, as a function of time, was fit to a first order polynomial. A histogram of the coefficients found in the fitting of the data from the different bunches and stores, is plotted in figure 1. Table I summarizes the characteristics of the fit to the bunch intensities *during low-β operation.*

Table I.[3]

Quantity	Particle	Value $\cdot 10^{-9}$	$\Sigma \cdot 10^{-9}$
N_0	p	62.6	13.1
N_0	$\bar{p}$	20.4	5.9
$dN/dt\|_{t=0}$	p	-0.40 / hour	0.19 / hour
$dN/dt\|_{t=0}$	$\bar{p}$	-0.17 / hour	0.10 / hour
"σ"	p	0.44	0.23
"σ"	$\bar{p}$	0.36	0.30

The fraction of the p or $\bar{p}$ lost per unit time seems quite comparable. The lifetime (defined as $-N/(dN/dt)$) of the bunch intensities is in excess of 100 hours. The first order fit described here has a bunch lifetime which decreases with time into the store.

If the data are fit to a second order polynomial then the bunch lifetime begins at greater than 50hours and reaches more than 100hours in 4-8 hours. The lifetime of the proton bunches is longer than the lifetime of the anti-proton bunches.

[3]The Σ given for the fitted coefficients gives an indication of the variation, over the many sets of data fitted, in the value of the fitted parameter. The quantity described as "σ" in the table is an indication of the error that would be assigned to the data to have the expected χ^2 for the fit.

Transverse Emittances

The transverse emittances (horizontal and vertical) of the 6 proton and 6 anti-proton bunches were measured by flying wires at C48 (horizontal and vertical wires) and A17 (horizontal wire). The measured σ of each bunch was converted into an emittance using values of the amplitude function β and the dispersion function η calculated by **TEVLAT**. (The calculation was done including the values of the high order multi-poles measured at **MTF**.) The emittance of each bunch was fit to a first order polynomial. The coefficients found in the fitting are histogrammed and shown in figure 2 and figure 3. Table II summarizes the characteristics of the fit to the bunch emittances *during low-β operation.*

Table II. - Transverse Emittance

Quantity	Particle	Value (mmmr)	Σ (mmmr)
$\epsilon_h\|_{t=0}$	p	19.5	3.2
$\epsilon_v\|_{t=0}$	p	21.8	4.4
$\epsilon_h\|_{t=0}$	$\overline{p}$	12.0	2.3
$\epsilon_v\|_{t=0}$	$\overline{p}$	14.5	2.9
$d\epsilon_h/dt\|_{t=0}$	p	+0.34 / hour	0.13 / hour
$d\epsilon_v/dt\|_{t=0}$	p	+0.35 / hour	0.20 / hour
$d\epsilon_h/dt\|_{t=0}$	$\overline{p}$	+0.30 / hour	0.10 / hour
$d\epsilon_v/dt\|_{t=0}$	$\overline{p}$	+0.30 / hour	0.19 / hour
"$\sigma - \epsilon_h$"	p	0.62	0.37
"$\sigma - \epsilon_v$"	p	1.4	1.5
"$\sigma - \epsilon_h$"	$\overline{p}$	0.56	0.42
"$\sigma - \epsilon_v$"	$\overline{p}$	1.23	1.61

The growth of the emittance is approximately the same for both p and $\bar{p}$ and in both transverse planes at about 0.3 mmmr/hour. The growth rate of the proton bunches is slightly larger than that of the anti-proton bunches.

The data for the vertical emittance reflects problems with the vertical wire during the run.

Bunch Length, Longitudinal Emittance and $\delta p/p$

The bunch lengths of the 6 proton and 6 anti-proton bunches were measured by the **SBD** (**S**ampled **B**unch **D**isplay). The data were recorded by the data logger and these data were averaged over a 15 minute interval and stored in the data base. From the measured bunch length, the calculated transition γ and a knowledge of the operating conditions of the TEVATRON (such as the energy and the *r.f.* voltage) the longitudinal emittance and the value of $\delta p/p$ can be calculated. [4] The data for each bunch were fit to a first order polynomial. The coefficients found in the fitting are histogrammed and plotted in figures 4-6. Tables III,IV,V summarize the characteristics of the fit to the data *during low-β operation.*

Table III.- Bunch Length.

Quantity	Particle	Value (cm)	Σ (cm)
L_0	p	50.0	2.4
L_0	$\bar{p}$	50.3	3.0
$dL/dt_{\ t=0}$	p	+0.56 / hour	0.18 / hour
$dL/dt_{\ t=0}$	$\bar{p}$	+0.62 / hour	0.17 / hour
"σ"	p	0.73	0.37
"σ"	$\bar{p}$	0.98	0.59

Table IV.- Longitudinal Emittance.

Quantity	Particle	Value (eV-s)	Σ (eV-s)
$\epsilon_l\|_{t=0}$	p	2.95	0.35
$\epsilon_l\|_{t=0}$	$\bar{p}$	2.91	0.40
$d\epsilon_l/dt\|_{t=0}$	p	$6.6\cdot10^{-2}$/ hour	$3.1\cdot10^{-2}$/ hour
$d\epsilon_l/dt\|_{t=0}$	$\bar{p}$	$6.9\cdot10^{-2}$/ hour	$2.6\cdot10^{-2}$/ hour
"σ"	p	0.11	0.12
"σ"	$\bar{p}$	0.13	0.14

[4]The average *r.f.* voltage for the protons is $\approx 4\%$ larger than that of the anti-protons. As a result, even though the anti-proton bunch length is, on the average, slightly larger than that of the protons, the longitudinal emittance ϵ_l and the $\delta p/p$ of the protons is, on average, slightly larger than that of the anti-protons

Table V.-$\delta p/p$

Quantity	Particle	Value (%)	Σ (%)
$\delta p/p_0$	p	$1.37 \cdot 10^{-2}$	$1.71 \cdot 10^{-3}$
$\delta p/p_0$	$\bar{p}$	$1.36 \cdot 10^{-2}$	$2.57 \cdot 10^{-3}$
$d(\delta p/p)/dt\|_{t=0}$	p	$1.60 \cdot 10^{-4}$/ hour	$1.47 \cdot 10^{-4}$ / hour
$d(\delta p/p)/dt\|_{t=0}$	$\bar{p}$	$1.60 \cdot 10^{-4}$/ hour	$8.4 \cdot 10^{-5}$ / hour
"σ"	p	$2.91 \cdot 10^{-4}$	$2.71 \cdot 10^{-4}$
"σ"	$\bar{p}$	$3.26 \cdot 10^{-4}$	$3.11 \cdot 10^{-4}$

Again we see that the proton and anti-proton bunches behave in a similar manner though the growth in the longitudinal emittance of the anti-protons is slightly larger than for protons. The bunch length grows typically by about 6mm/hour. The corresponding change in $\delta p/p$ is approximately $1.60 \cdot 10^{-4}$%/hour. The growth of the longitudinal emittance is $\approx$ 0.06eV-s/hour.

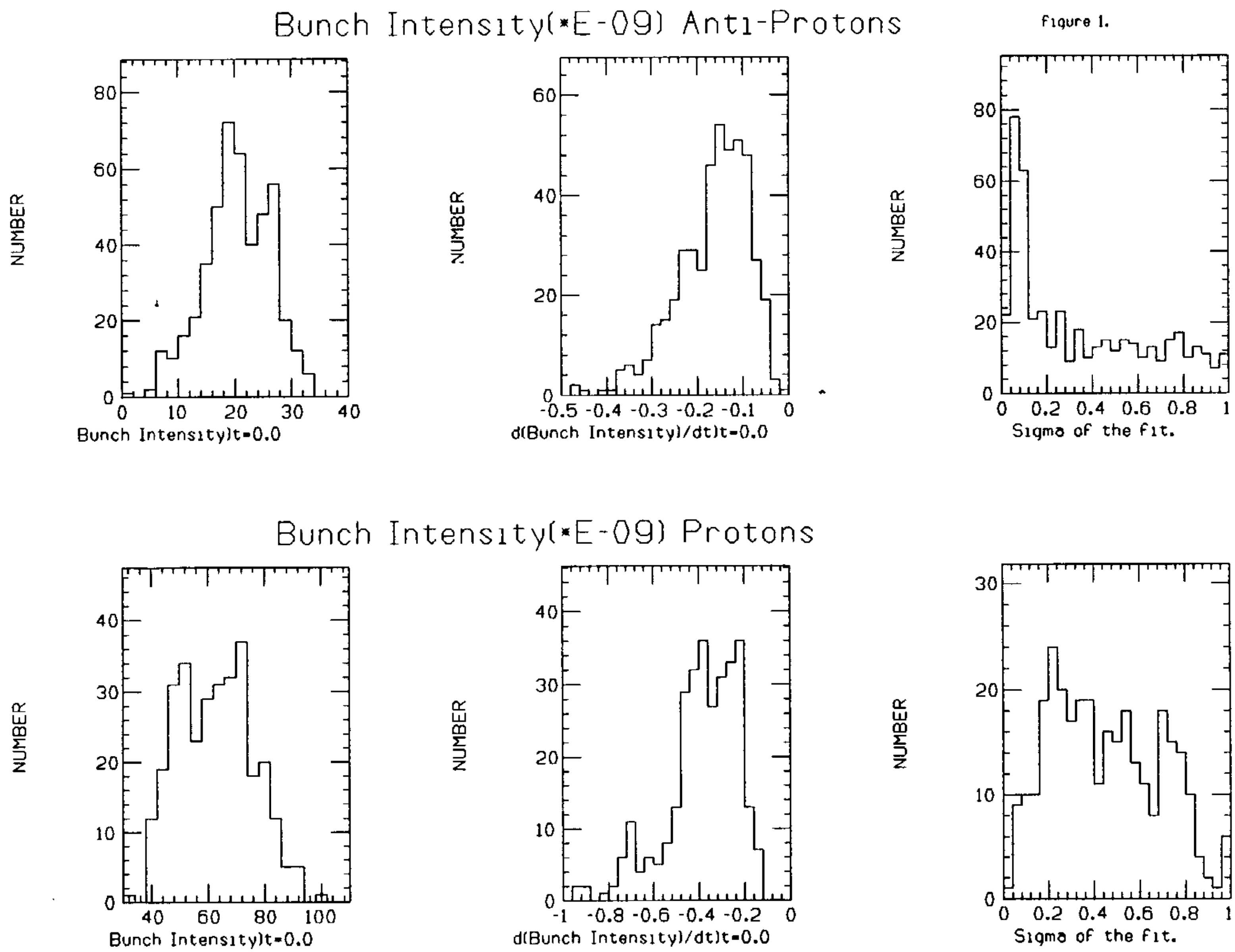
Luminosity

The interaction rate at B0 has been measured by the CDF collaboration, and they have expressed the rate as a luminosity using a number of assumptions. This "measured" luminosity is referred to as C:B0LUMP and is known to exhibit a short lifetime shortly after low-β is reached. The lifetime of C:B0LUMP is observed to increase as the store evolves.

The values of C:B0LUMP provided by CDF have been averaged over a fifteen minute interval and stored in the data base. The values of C:B0LUMP recovered from the data base have been fit to a second order polynomial in the time after the TEVATRON reached low-β. [5] The fit to these data (figure 7) shows an initial lifetime of the order of 14hours rising to more than 17hours after the first hour of collisions. After 10 hours the luminosity lifetime is on the order of 24hours.

The luminosity lifetime is much smaller than the lifetime one would calculate if the only time dependence was due to the lifetime of the bunch intensities.

[5] Please note that since the value of C:B0LUMP does not require the flying wires the data are available *right* after we reach low-β.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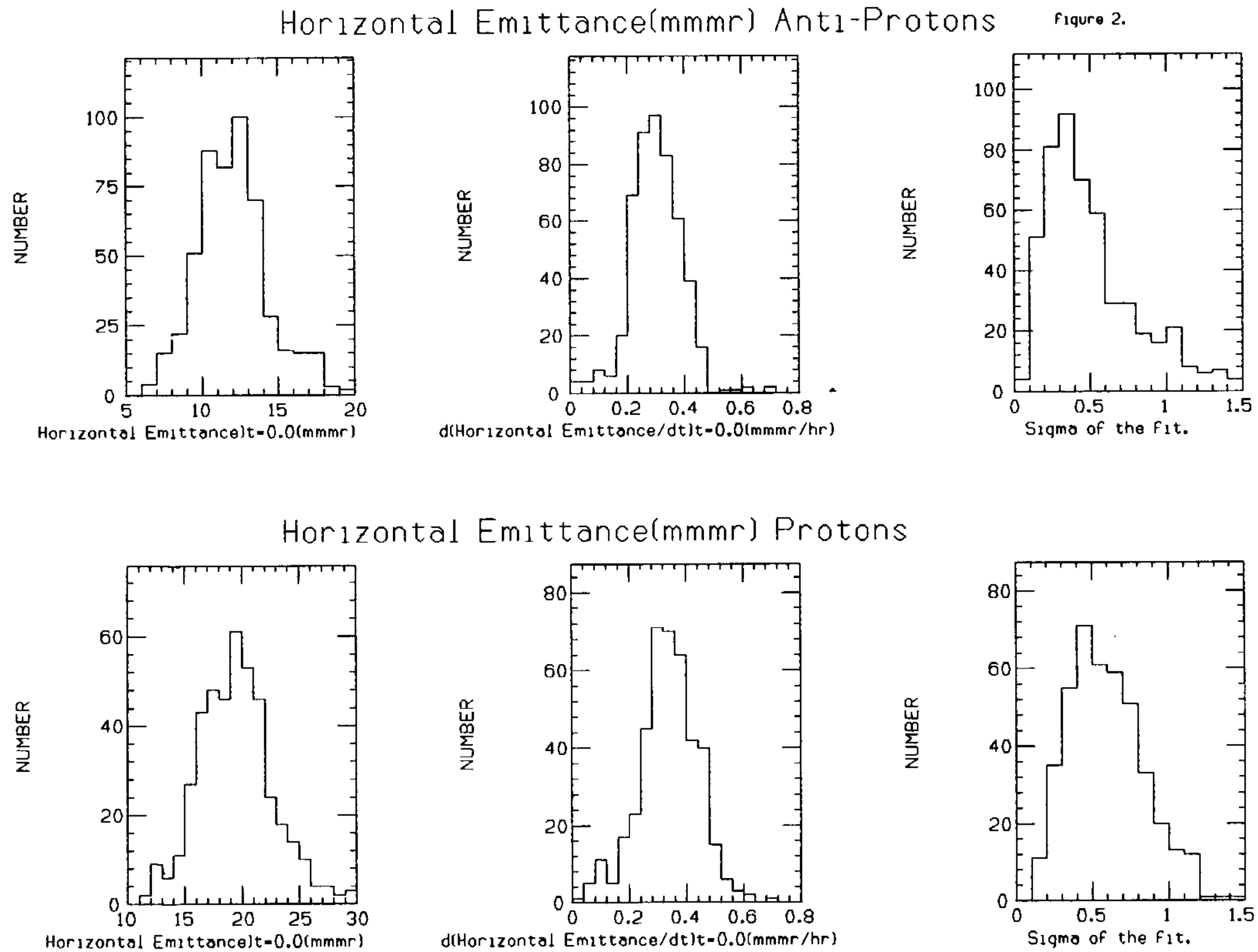
d(Bunch Intensity)/dt)t=0.0
Sigma of the fit.
Bunch Intensity(*E-09) Protons
NUMBER
Bunch Intensity)t=0.0
d(Bunch Intensity)/dt)t=0.0
Sigma of the fit.

figure 1.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Sigma of the Fit.
Horizontal Emittance(mmmr) Protons
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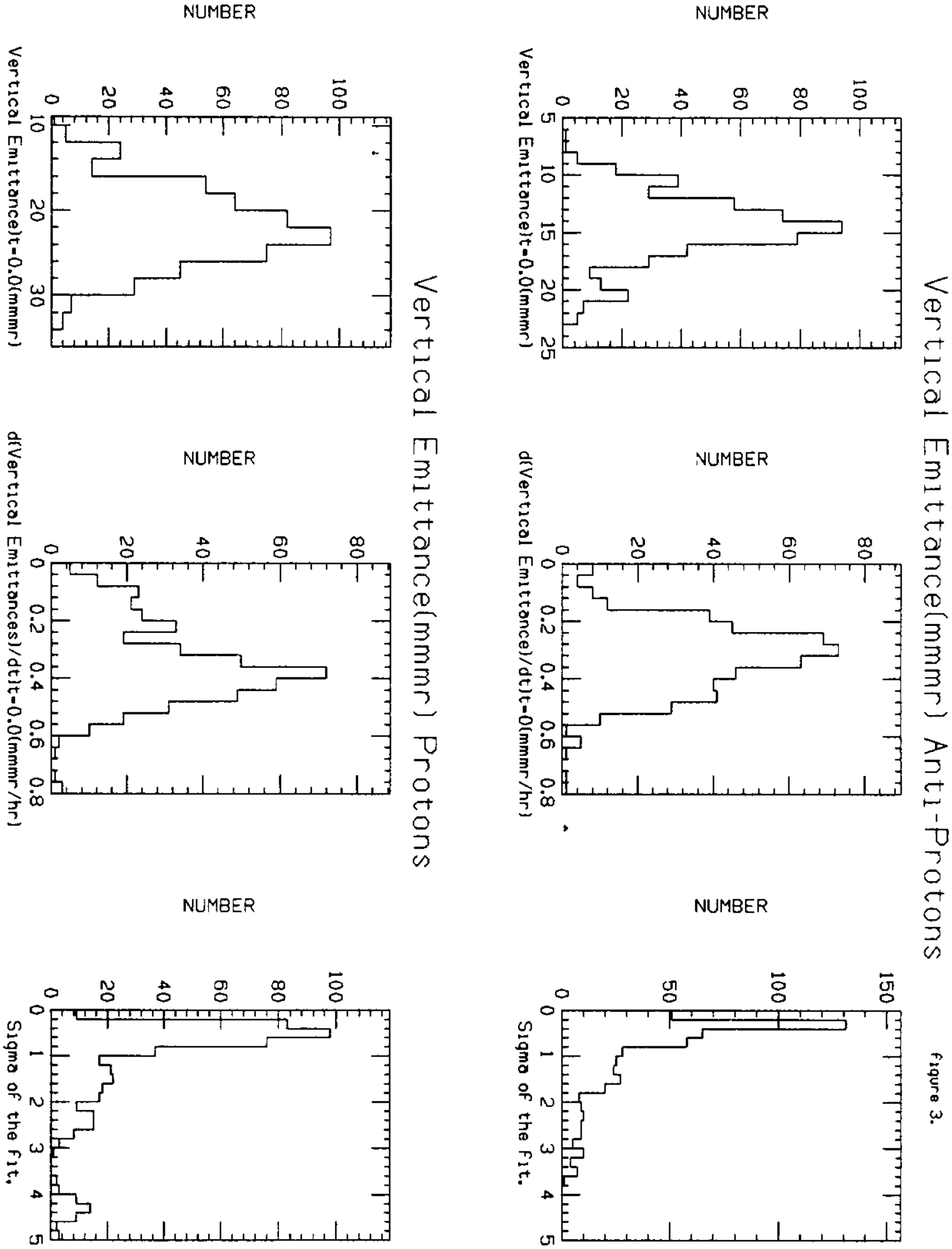
d(Horizontal Emittance/dt)t=0.0(mmmr/hr)
Sigma of the Fit.

Figure 2.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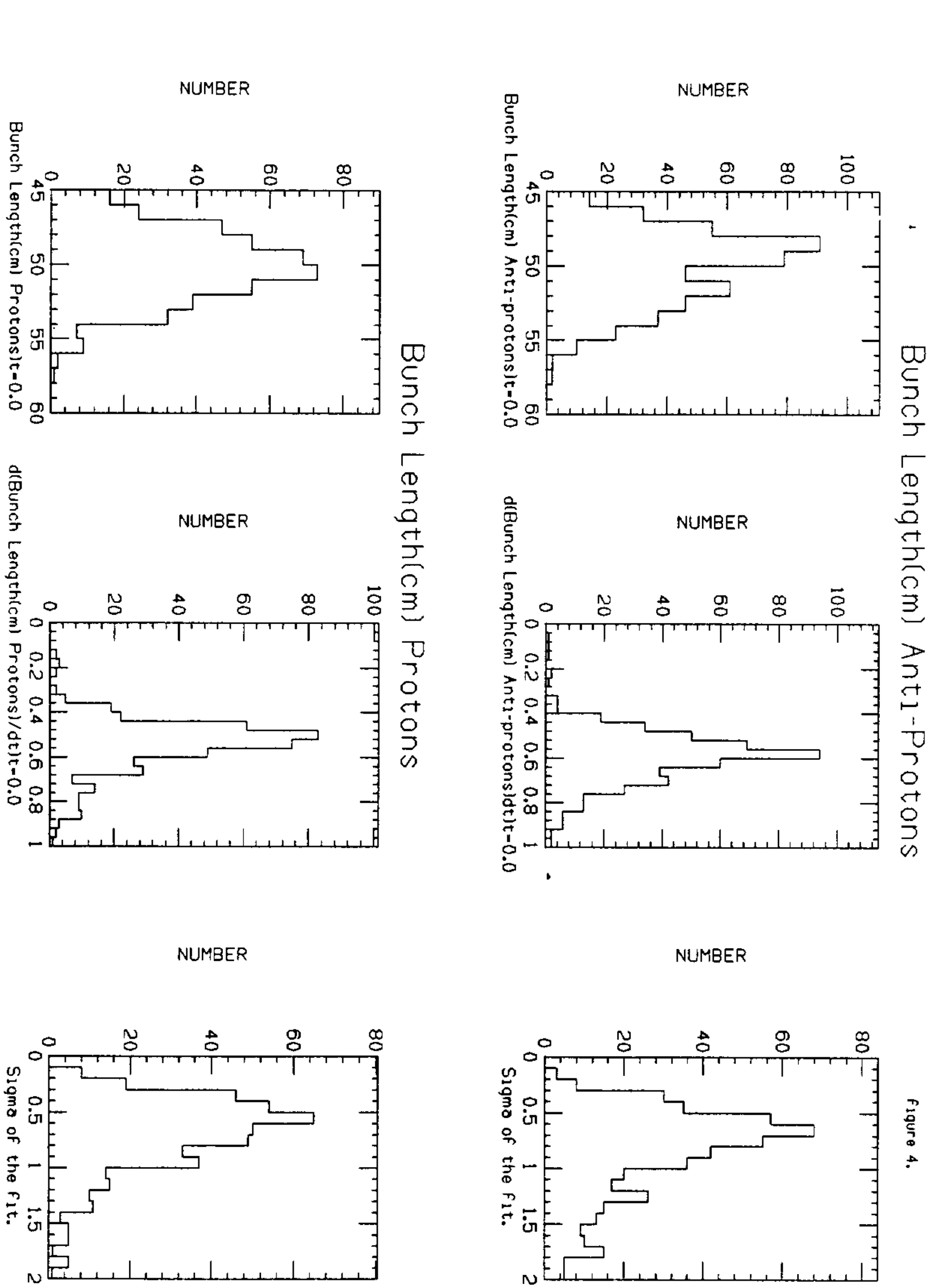
Vertical Emittance(mmmr) Protons
d(Vertical Emittances)/dt@t=0.0(mmmr/hr)

figure 3.


Bunch Length(cm) Anti-Protons
Bunch Length(cm) Protons
Figure 4.
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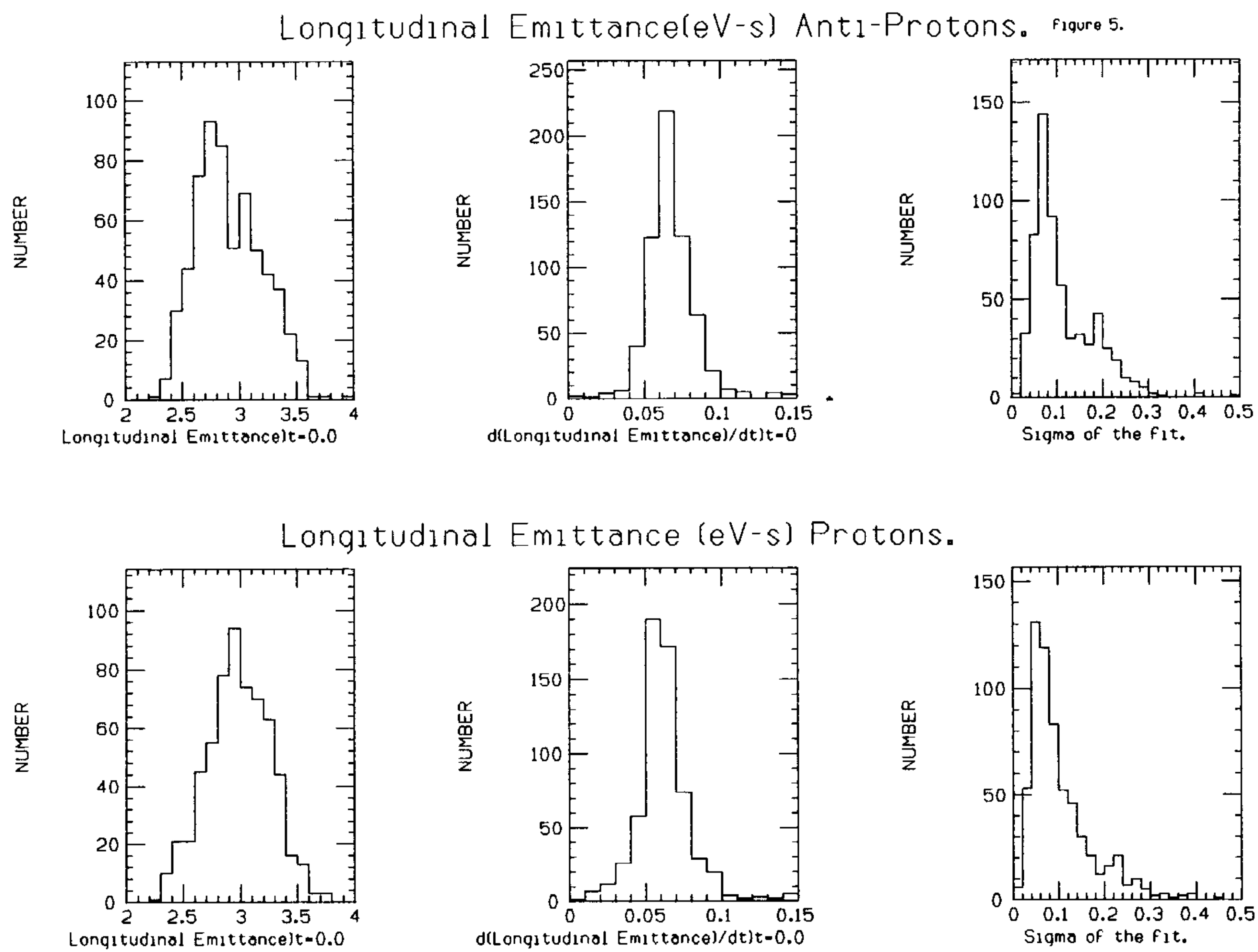
Sigma of the fit.
Bunch Length(cm) Protons|t=0.0
d(Bunch Length(cm) Protons)/dt|t=0.0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NUMBER
Sigma of the fit.
Longitudinal Emittance (eV-s) Protons.
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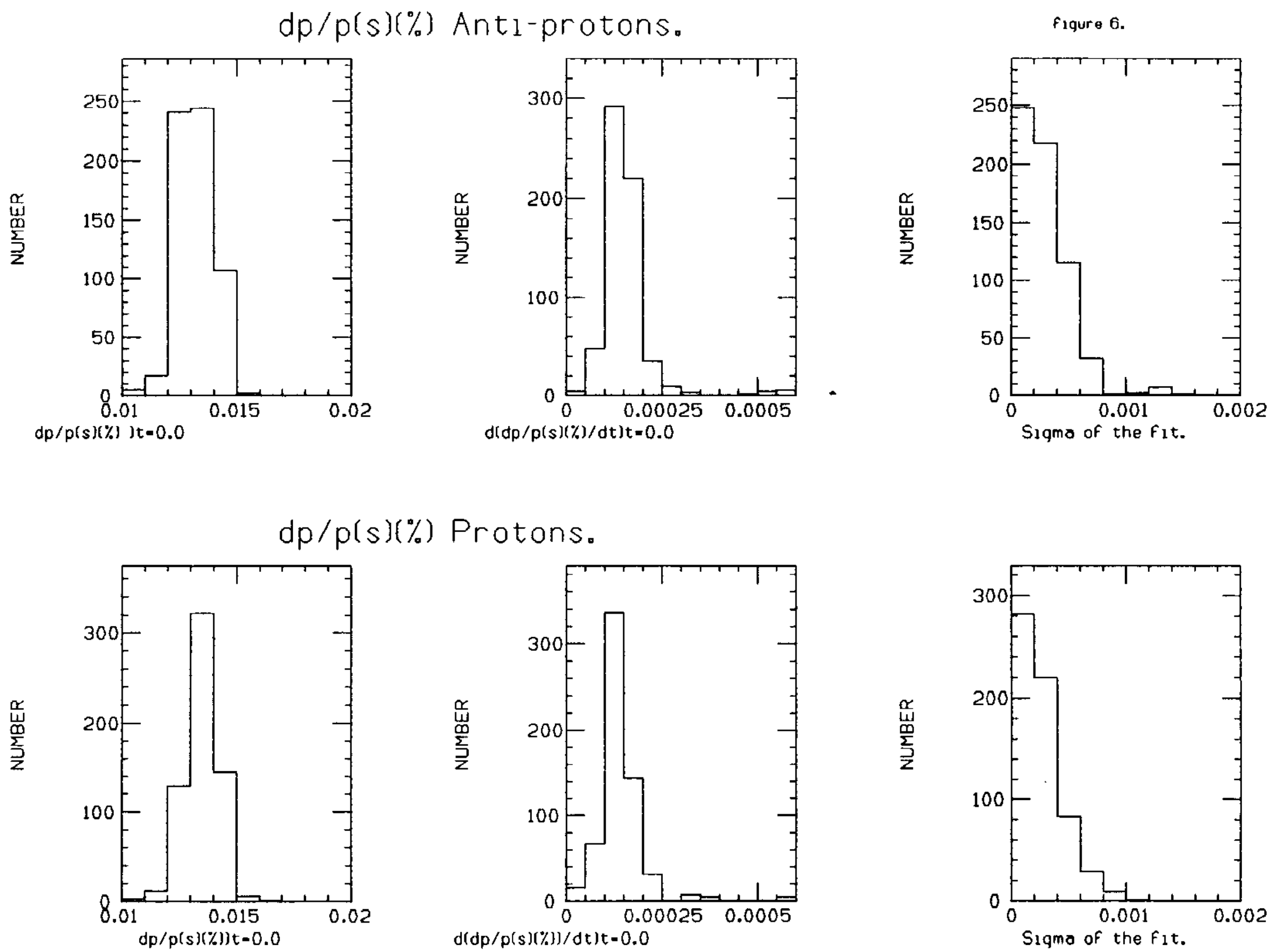
NUMBER
d(Longitudinal Emittance)/dt)t=0.0
NUMBER
Sigma of the fit.

Figure 5.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Sigma of the fit.
dp/p(s)(%) Protons.
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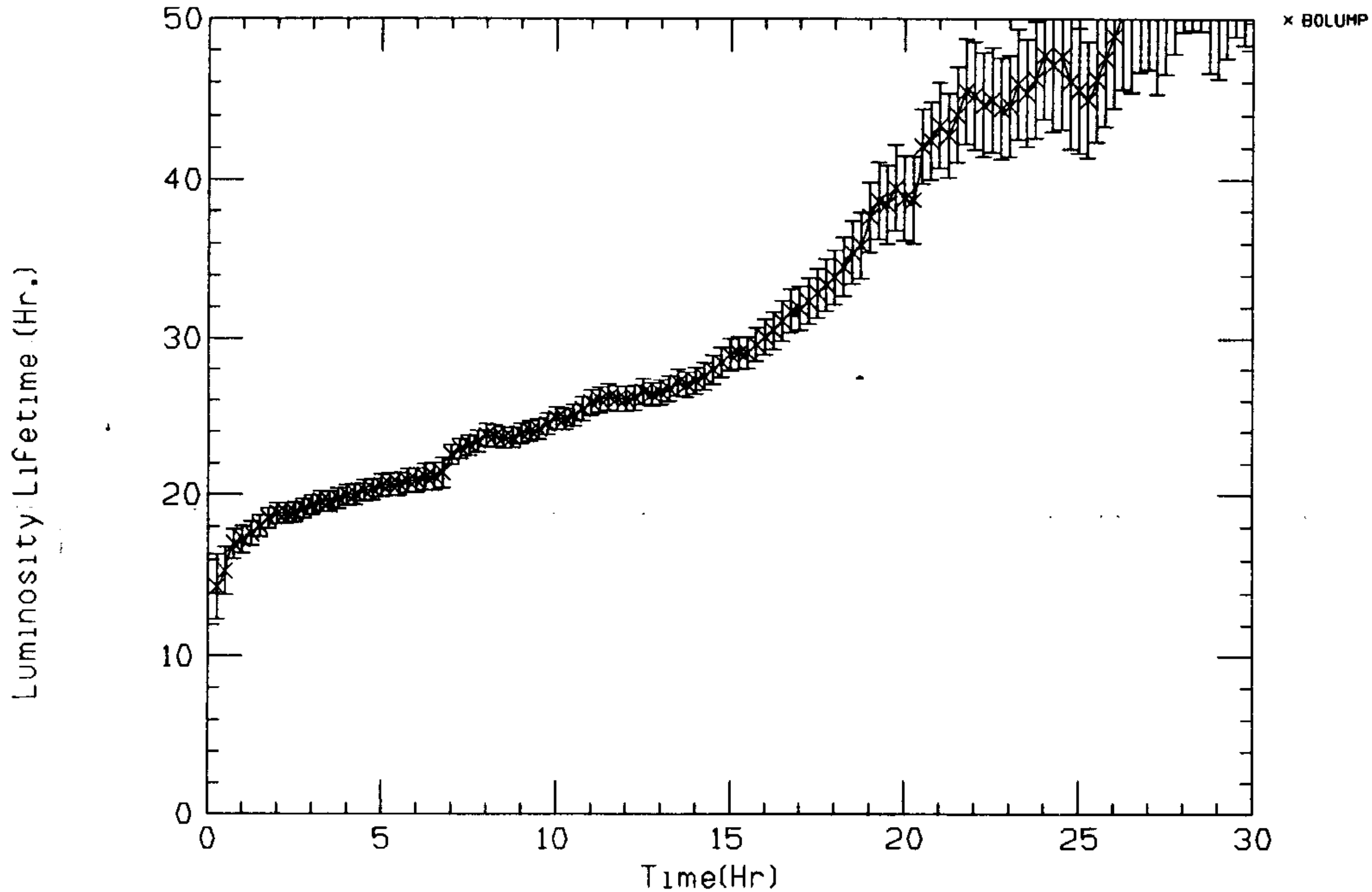
Sigma of the fit.

figure 6.

Luminosity Lifetime (Hr.) VS TIME

figure 7



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